



Jet Propulsion Laboratory



From the roar of pioneering Space Age rockets to the soft whir of servos on 21st-century robot explorers on Mars, the Jet Propulsion Laboratory's spacecraft have blazed the trail to the planets and the universe beyond for nearly 60 years.

The United States first entered space with the 1958 launch of the satellite Explorer 1, built and controlled by JPL. From orbit, Explorer 1's voyage yielded immediate scientific results — the discovery of the Van Allen Radiation Belts — and provided new perspective for studying Earth as a planet. This pivotal space flight led to the creation of NASA and would be followed by decades of major discoveries about Earth and its neighboring bodies as JPL's robotic spacecraft have traversed the solar system.

Innovative technology from JPL has taken humanity far beyond regions of space where we can actually travel ourselves. The most distant human-made objects, Voyagers 1 and 2, were built and are operated by JPL. Now in their fourth decade of exploration, the Voyagers have pressed beyond our farthest planets and continue to return their findings about unexplored space through the antennas of the Deep Space Network, also managed by JPL. From JPL's labs and clean rooms come telescopes and cameras that have extended our vision to unprecedented

depths and distances, peering into the hearts of clouds where new stars are born, and even toward the beginning of time at the edge of the universe.

Meeting the challenges of robotic space exploration has resulted in new knowledge that has kept JPL a world leader in science and technology. The tools JPL has developed for space exploration have also proved invaluable in providing new insights and discoveries in studies of Earth, its atmosphere, climate, oceans, geology and the biosphere. The ongoing invention of ever more-sensitive space sensors has also resulted in a myriad of technology applications widely used for medical, industrial and commercial uses on Earth.

JPL is a federally funded research and development center managed by the California Institute of Technology for the National Aeronautics and Space Administration.

JPL's Beginnings

JPL's history dates to the 1930s, when Caltech professor Theodore von Kármán oversaw pioneering work in rocket propulsion. Von Kármán was head of Caltech's Guggenheim Aeronautical Laboratory. Several of his graduate students and assistants gathered to test a primitive rocket engine in a dry

NASAfacts

riverbed wilderness area in the Arroyo Seco, a dry canyon wash north of the Rose Bowl in Pasadena, California. Their first rocket firing took place there on October 31, 1936.

After the Caltech group's successful rocket experiments, von Kármán, who also served as a scientific adviser to the U.S. Army Air Corps, persuaded the Army to fund development of strap-on rockets (called "jet-assisted takeoff") to help overloaded Army airplanes take off from short runways. The Army helped Caltech acquire land in the Arroyo Seco for test pits and temporary workshops. Airplane tests at nearby air bases proved the concept and tested the designs. By this time, World War II had begun and the rockets were in demand.

As the group wound up the work on the jet-assisted takeoff rockets, the Army Air Corps asked von Kármán for a technical analysis of the German V-2 program just discovered by Allied intelligence. He and his research team proposed a U.S. research project to understand, duplicate and reach beyond the guided missiles beginning to bombard England. In the proposal, the Caltech team referred to their organization for the first time as "the Jet Propulsion Laboratory."

Funded by Army Ordnance, the Jet Propulsion Laboratory's early efforts would eventually involve technologies beyond those of aerodynamics and propellant chemistry, technologies that would evolve into tools for space flight, secure communications, spacecraft navigation and control, and planetary exploration.

The team of about 100 rocket engineers began to expand, and the team began tests in the California desert of small unguided missiles, named Private, that reached a range of nearly 18 kilometers (about 11 miles). They experimented with radio telemetry from missiles, and began planning for ground radar and radio sets. By 1945, with a staff approaching 300, the group had begun to launch test vehicles from White Sands, New Mexico, to an altitude of 60 kilometers (200,000 feet), monitoring performance by radio.

Control of the guided missile was the next step, requiring two-way radio as well as radar and a primitive computer (using radio tubes) at the ground station. The result was JPL's answer to the German V-2 missile, named Corporal, first launched in May 1947, about two years after the end of war with Germany.

Developing a missile that would fly and survive in the field involved testing its aerodynamic design and durability under vibration and other stresses. The team developed a supersonic wind tunnel and an array of environmental test technologies, all of which had wider use and came to support outside customers. Developing so complex a device as a missile to fly unaided and beyond reach of repair meant a new degree of quality, new test techniques and a new discipline called system engineering.

Subsequent Army work further sharpened the technologies of communications and control, of design and test and performance analysis. This made it possible for JPL to develop the

flight and ground systems and finally to fly the first successful U.S. space mission, Explorer 1. The entire three-month effort began in November 1957 and culminated with the successful launch on January 31, 1958.

On December 3, 1958, two months after NASA was created by Congress, JPL was transferred from Army jurisdiction to that of the new civilian space agency. It brought to the new agency experience in building and flying spacecraft, an extensive background in solid and liquid rocket propulsion systems, guidance, control, systems integration, broad testing capability, and expertise in telecommunications using low-power spacecraft transmitters and very sensitive Earth-based antennas and receivers.

The Laboratory now covers some 72 hectares (177 acres) adjacent to the site of von Kármán's early rocket experiments.

Planetary Exploration

In the 1960s, JPL began to conceive and execute robotic spacecraft to explore other worlds. This effort began with the Ranger and Surveyor missions to the moon, paving the way for NASA's Apollo astronaut lunar landings. The successful Ranger missions were Ranger 7, 8 and 9, launched in 1964 and 1965, which took photos of the moon as they descended toward an intentional impact. In 1966 through 1968, Surveyor 1, 3, 5, 6 and 7 made soft-landings on the moon. During that same period and through the early 1970s, JPL carried out Mariner missions to Mercury, Venus and Mars.

Mariner 2 became the first spacecraft to fly by another planet following its launch August 27, 1962, to Venus (Mariner 1 was lost because of a launch vehicle error). Other successful planetary flybys were conducted by 1964's Mariner 4 to Mars, 1967's Mariner 5 to Venus, and 1969's Mariner 6 and 7 to Mars. In 1971, Mariner 9 became the first spacecraft to orbit another planet when it was sent to Mars.

Mariner 10 was the first spacecraft to use a "gravity-assist" boost from one planet to send it on to another — a key innovation in spaceflight that would later enable the exploration of outer planets that would have otherwise been unreachable. Mariner 10's launch in November 1973 delivered the spacecraft to Venus in February 1974, where a gravity-assist swingby allowed it to fly by Mercury in March and September that year.

The first search for life on Mars was conducted in 1975 when NASA launched the Viking mission's two orbiter spacecraft and two landers. The elaborate mission was divided between several NASA centers and private U.S. aerospace firms, with JPL building the Viking orbiters, conducting mission communications and eventually assuming responsibility for management of the mission.

Credit for the single mission that has visited the most planets goes to JPL's Voyager project. Launched in 1977, the twin Voyager 1 and Voyager 2 spacecraft flew by the planets Jupiter

(1979) and Saturn (1980–81). Voyager 2 then went on to an encounter with the planet Uranus in 1986 and a flyby of Neptune in 1989. Early in 1990, Voyager 1 turned its camera around to capture a series of images assembled into a “family portrait” of the solar system. Still communicating their findings as they speed out toward interstellar space, the Voyagers are expected to have enough power to continue communicating information about the sun’s energy field until approximately the year 2025. In February 1998, Voyager 1 passed NASA’s Pioneer 10 to become the most distant human-made object in space. In August 2012, Voyager 1 crossed the heliopause to become the first spacecraft to enter interstellar space.

In 1989 and 1990, NASA’s space shuttle helped launch three JPL-managed solar system exploration missions: Magellan to Venus, Galileo to Jupiter and Ulysses to study the sun’s poles.

Magellan used a sophisticated imaging radar to pierce the cloud cover enshrouding Venus and map the planet’s surface. Magellan was carried into Earth orbit in May 1989 by space shuttle Atlantis. Released from the shuttle’s cargo bay, Magellan was propelled by a booster engine toward Venus, where it arrived in August 1990. It completed its third 243-day period mapping the planet in September 1992. Magellan mapped variations in Venus’s gravity field before the mission ended in October 1994. At the conclusion of the mission, flight controllers commanded Magellan to dip into the atmosphere of Venus in a test of aerobraking — a technique for using atmospheric drag to slow spacecraft that has since been used in other planetary missions.

The Galileo mission began in October 1989 when it was carried into Earth orbit on space shuttle Atlantis and then sent on its interplanetary flight path via an Inertial Upper Stage booster. Relying on gravity assist swingbys to reach Jupiter, Galileo flew past Venus once and Earth twice. Along the way, Galileo flew by the asteroid Gaspra in October 1991 and the asteroid Ida in August 1993. On its final approach to the giant planet, Galileo observed Jupiter being bombarded by fragments of the broken-up comet Shoemaker–Levy 9. On July 12, 1995, Galileo separated from its atmospheric probe and the two spacecraft flew in formation to their final destination.

On December 7, 1995, Galileo fired its main engine to enter Jupiter orbit and collected data radioed from the probe during its parachute descent into the planet’s atmosphere. During its two-year prime mission, Galileo conducted 10 targeted flybys of Jupiter’s major moons. In December 1997, the spacecraft began a first extended mission, which featured eight flybys of Jupiter’s icy moon Europa and two of the volcanic moon Io. A second extended mission began in early 2000, including flybys of the moons Io, Ganymede and Callisto, plus coordinated observations with the Cassini spacecraft as Cassini flew past Jupiter in December 2000 for a gravity assist to reach Saturn. On September 21, 2003, after 14 years in space and eight years orbiting Jupiter, Galileo ended its mission by plunging into the giant planet’s

atmosphere — a maneuver designed to avoid any chance of Galileo contaminating Jupiter’s moons with bacteria from Earth.

NASA’s shuttle fleet again launched a probe bound for other parts of the solar system when the space shuttle Discovery carried aloft Ulysses in October 1990. A joint mission between NASA and the European Space Agency, this project for the first time sent a spacecraft out of the ecliptic — the plane in which Earth and other planets orbit the sun — to study the sun’s north and south poles. Ulysses first flew by Jupiter in February 1992, where the giant planet’s gravity flung it into an unusual solar orbit nearly perpendicular to the ecliptic plane. Ulysses made a total of three passes by the sun’s north and south poles in 1994–5, 2000–1 and 2006–7. After it operated for 18 years, final communication with Ulysses took place in June 2009.

The mission of Mars Observer, launched aboard a Titan III rocket in September 1992, ended with disappointment in August 1993 when contact was lost with the spacecraft shortly before it was to enter orbit around Mars. Some science instruments from Mars Observer were later flown on Mars Global Surveyor.

The next JPL planetary launches were those of Mars Global Surveyor and Mars Pathfinder, launched in November and December 1996, respectively. Mars Pathfinder put a lander and rover on the surface of the Red Planet in a highly successful landing July 4, 1997; the project fulfilled all the objectives of its prime mission and lasted considerably longer than originally designed before the lander fell silent in September 1997. Mars Global Surveyor went into orbit around the Red Planet in September 1997, and spent a year and a half lowering its orbit using the technique of aerobraking. The spacecraft made highly detailed maps of the Martian surface until its last communication with Earth in November 2006.

A disappointment at Mars occurred in late 1999, with the loss of the orbiter and lander developed and launched under the Mars ’98 project — named Mars Climate Orbiter and Mars Polar Lander, respectively. Climate Orbiter entered the planet’s atmosphere too low and did not survive orbit insertion in September 1999. Polar Lander and two Deep Space 2 microprobes piggybacking on it to Mars were lost during arrival at the planet in December 1999.

An orbiter named Mars Odyssey was launched in April 2001, and arrived at the Red Planet in October of that year. After completing its four-year prime mission, Odyssey has continued to orbit the planet, examining what Mars is made of, detecting water and shallow buried ice, and studying the radiation environment in space.

The next mission to that planet, the Mars Exploration Rover project, sent a pair of robotic geologists to sites halfway around Mars from each other. Spirit was launched in June 2003 and landed in January 2004 inside a Connecticut-sized crater named Gusev. Opportunity was launched in July 2003 and landed in January

2004 inside a backyard-sized crater informally called “Eagle.” Originally designed to operate for three months, the rovers far exceeded their expected lifetimes and distances traveled. Spirit functioned until 2010, while Opportunity continues to function today. Each found evidence of long-ago Martian environments where water was active and conditions may have been suitable for life.

The next Mars mission was Mars Reconnaissance Orbiter, launched in August 2005 with the most powerful telescopic camera ever sent to another planet, plus five other scientific instruments. In 2008, the Mars Phoenix lander set down on the frozen terrain near the planet’s north pole, and spent the next five months digging trenches with a robotic arm — establishing that there is in fact a phenomenal amount of water locked up in the form of ice near the Martian north pole.

In 2011, JPL’s Mars Science Laboratory mission carrying the Curiosity rover was launched to the Red Planet. Curiosity landed in 2012 using a novel system called the Sky Crane to set it down gently onto the surface in Gale Crater. Curiosity spent two years in motion inside the crater before arriving in September 2014 at the base of Mount Sharp, its ultimate destination.

In 2018, the InSight mission will send to Mars a lander that will drill beneath the surface to investigate the Red Planet’s interior structure. The mission is designed to give scientists a better understanding of Mars’ evolution as a rocky planet. Two years later, the Mars 2020 mission will send the most sophisticated rover ever built to investigate key questions about the habitability of Mars, and assess natural resources and hazards in preparation for future human expeditions to the Red Planet. It will collect and store rock and soil samples potential return to Earth in the future.

JPL designed, built and is flying the Cassini–Huygens mission to Saturn, launched in October 1997. Carrying a record number of 12 instruments, Cassini arrived at Saturn in June 2004, and began an intensive study of Saturn’s rings, its moons and magnetosphere. Shortly after its arrival, Cassini discovered new moons, a new ring and a new radiation belt around Saturn. Cassini delivered a probe named Huygens, provided by the European Space Agency, which descended to the surface of Titan, Saturn’s largest moon, in January 2005. Titan appears to boast organic chemistry possibly like that which led to the existence of life on Earth. En route to Saturn, Cassini flew by Venus in April 1998 and June 1999 and conducted a Jupiter flyby in December 2000. Now in its second extended mission, Cassini is making the first observations of a complete seasonal period for Saturn and its moons before completing its tour with a dive into the giant planet in September 2017.

In 1999, NASA launched a JPL-teamed mission called Stardust under the space agency’s Discovery program of low-cost missions. Flying by comet Wild-2 in January 2004, Stardust collected dust and volatile materials that were returned to Earth in a capsule that parachuted to a landing on a dry lake bed in Utah in

January 2006. The spacecraft was then reprogrammed to carry out an extended mission, called Stardust-NExT, that took it on a flyby of comet Tempel 1 in February 2011.

JPL also provided project management for another Discovery mission, Genesis. Launched in August 2001, Genesis collected samples of charged particles in the solar wind and returned them to Earth in September 2004. Although the capsule’s parachutes did not deploy, scientists achieved most of their science objectives with samples recovered from the capsule.

In addition, JPL managed a Discovery mission called Deep Impact that propelled a large copper projectile into the surface of comet Tempel 1, creating a crater to reveal the composition and structure of the comet nucleus. Launched in January 2005, Deep Impact arrived at the comet in July of that year. The spacecraft was then redirected to carry out an extended mission called EPOXI, under which it made observations in search of planets orbiting other stars and was directed to fly by comet Hartley 2 in late 2010. A comet was also the destination for a JPL instrument called the Microwave Instrument on the Rosetta Orbiter, or Miro, which is carried by a European Space Agency craft launched in February 2004. Rosetta went into orbit around comet 67P/Churyumov–Gerasimenko and followed along as the comet made its closest approach to the sun.

A protoplanet and a dwarf planet were the destinations for Dawn, the first spacecraft ever designed to orbit two different bodies after leaving Earth. This mission under NASA’s Discovery program launched in September 2007; Dawn arrived at Vesta in July 2011, then departed in September 2012 for Ceres, which it reached in 2015.

Another major initiative that led to a new breed of NASA spacecraft was New Millennium, designed to flight-test new technologies so that they can be reliably used in science missions of the 21st century. The first New Millennium spacecraft, Deep Space 1, was launched in October 1998 to test an ion engine and 11 other new technologies. Deep Space 1 tested autonomous navigation and two advanced science instruments when it flew by the asteroid 9969 Braille in July 1999. After its primary mission, Deep Space 1 gathered images and other information from a bonus September 2001 flyby of comet Borrelly. Under Deep Space 2, two microprobes to test the Martian soil for water vapor piggybacked on Mars Polar Lander, but were lost at arrival in December 1999. The New Millennium program also includes deep space and Earth-orbiting missions managed by other NASA centers.

Jupiter became the target for a new spacecraft mission when Juno launched in August 2011. Planned to enter orbit July 4, 2016, Juno for the first time will peer below Jupiter’s dense cover of clouds to answer questions about the gas giant and the origins of our solar system. Juno’s primary goal is to reveal the story of Jupiter’s formation and evolution. Using long-proven technologies on a spinning spacecraft placed in an elliptical polar

orbit, Juno will observe Jupiter's gravity and magnetic fields, atmospheric dynamics and composition, and evolution.

In September 2011, the twin Gravity Recovery and Interior Laboratory, or Grail, spacecraft launched to Earth's moon to create the most accurate gravitational map of the moon to date, which, when combined with topographic data, can provide insight into the moon's internal structure, composition and evolution. The two spacecraft orbited for nearly a year before completing their mission by impacting the moon.

A major new mission to Jupiter's moon Europa is being developed for the 2020s. As planned, the mission would conduct detailed reconnaissance of Jupiter's moon Europa and investigate whether the icy moon could harbor conditions suitable for life. It would achieve this by placing a spacecraft in orbit around Jupiter in order to perform a detailed investigation of the giant planet's moon Europa — a world that shows strong evidence for an ocean of liquid water beneath its icy crust and which could host conditions favorable for life. The mission would send a highly capable, radiation-tolerant spacecraft into a long, looping orbit around Jupiter to perform repeated close flybys of Europa.

The Laboratory created the Near-Earth Asteroid Tracking system, an automated system used at an Air Force observatory in Hawaii to scan the skies for asteroids or comets that could threaten Earth. In 1999, the project made its first observations from a second site, the 1.2-meter-diameter (48-inch) Oschin telescope on Palomar Mountain, California. In 1998, NASA designated JPL as home of the agency's Near-Earth Objects Office to coordinate observations of Earth-crossing asteroids and comets by various NASA scientists. Near-Earth objects have also been studied in an extended mission by the Wide-field Infrared Survey Explorer.

JPL also has a major role in NASA's Asteroid Redirect Mission, a potential future space mission that would rendezvous with a large near-Earth asteroid and use robotic arms with anchoring grippers to retrieve a 6-meter boulder from the asteroid. In addition to directing spacecraft that visit planets, asteroids and comets, JPL scientists are active in many programs of observations from the ground.

Earth Science

In the late 1970s, JPL engineers and scientists realized that the sensors they were developing for interplanetary missions could be turned upon Earth itself to better understand our home planet. This has led to a series of highly successful Earth-monitoring missions that have evolved into a major segment of the Laboratory's activities, now sponsored by NASA's Science Mission Directorate.

In 1978, JPL built an experimental satellite called Seasat to test a variety of oceanographic sensors including imaging radar, altimeters, radiometers and scatterometers. Many of the later Earth-monitoring instruments developed at JPL owe their legacy to the Seasat mission.

The imaging radar flown on Seasat led to a pair of missions flown on the space shuttle, 1981's Shuttle Imaging Radar-A and 1984's Shuttle Imaging Radar-B. These were followed by Spaceborne Imaging Radar-C, an experiment teamed with the German/Italian X-Band Synthetic Aperture Radar and flown on the space shuttle twice in 1994. This mission's goal was to study a variety of scientific disciplines — geology, hydrology, ecology and oceanography — by comparing the radar images to data collected by teams of people on the ground. Imaging radar was reflown on the space shuttle under the Shuttle Radar Topography Mission in February 2000 to create the world's most accurate topographic map.

Seasat also tested an altimeter that measured sea-level heights from space. This concept led to a full-scale satellite mission, Topex/Poseidon, developed jointly by JPL and the French space agency. The oceanographic satellite, launched in August 1992 on an Ariane 4 rocket from Kourou, French Guiana, provided scientists with unprecedented insight into global climate and ocean interactions, currents, eddies, and new details about the global ocean seafloor before its mission ended in 2005. It was followed by three follow-on collaborations with France: Jason 1, launched in 2001 and active until 2013; and Jason 2 and Jason 3, launched in 2008 and 2016, respectively, and both currently operating.

Another mission with heritage in Seasat was the JPL-built NASA Scatterometer, an instrument that measures near-surface ocean winds from space. This instrument was launched in August 1996 on the Advanced Earth Observing Satellite prepared by Japan's National Space Development Agency, and continued operating until the satellite failed in early 1997. JPL prepared a rapid replacement, QuikScat, which was launched in 1999 from Vandenberg Air Force Base, California, carrying a scatterometer called SeaWinds that collected data until 2010. A follow-on SeaWinds scatterometer was launched on a Japanese satellite in 2002, but the host satellite stopped functioning later that year. In 2014, another scatterometer instrument, RapidScat, was launched and installed on the International Space Station.

JPL also designed and built an instrument called the Microwave Limb Sounder that studies the chemistry of Earth's upper atmosphere, relaying important data on topics such as ozone depletion. Early versions flew as payloads on the space shuttle, followed by an instrument onboard NASA's Upper Atmosphere Research Satellite launched in September 1991. Currently, a new-generation version of the instrument is flying on NASA's Aura satellite launched in 2004 as part of the agency's Earth Observing System program.

JPL is responsible for several other instruments being flown under the Earth Observing System program. They include the Multi-angle Imaging SpectroRadiometer, launched on NASA's Terra satellite in December 1999 to study the role of clouds in global climate; the Advanced Spaceborne Thermal Emission and Reflection Radiometer, also carried on the Terra satellite to image

Earth in various parts of the color spectrum; the Atmospheric Infrared Sounder, launched aboard NASA's Aqua satellite in May 2002, which relays data on temperature and humidity in the atmosphere in order to help understand how heat is exchanged between land, air, sea and the atmosphere; and the Tropospheric Emission Spectrometer, launched in 2004 aboard the Aura satellite, which is studying the troposphere — the lowest region of Earth's atmosphere — and tracking trends in atmospheric chemistry on a global basis.

The Active Cavity Radiometer Irradiance Monitor, or Acrim, is an instrument that measures the sun's total output of optical energy from ultraviolet to infrared wavelengths — called the total solar irradiance — an important factor in the study of Earth's climate. The instrument was flown on several shuttle missions and satellites in the 1980s and 1990s. A dedicated satellite called AcrimSat was launched in December 1999.

Clouds are the object of study for the CloudSat satellite, launched in 2006 — the first spacecraft to examine clouds on a global basis.

A JPL-teamed mission called the Gravity Recovery and Climate Experiment, or Grace, launched twin satellites in March 2002 to conduct global high-resolution studies of Earth's gravity field. A follow-on to the mission is being developed for launch in 2017.

JPL provided project management for the Solar Mesosphere Explorer, a satellite launched in 1981 to investigate the processes that create and destroy ozone in Earth's upper atmosphere.

Among other JPL-developed missions under NASA's Earth System Science Pathfinder, the Orbiting Carbon Observatory was designed to make the first space-based measurements of atmospheric carbon dioxide to gauge its impact on climate. The satellite was launched in 2009, but was lost when the launch vehicle's nose cone, or fairing, failed to open properly. A replacement, Orbiting Carbon Observatory 2, was launched in 2014 and continues to operate. A follow-on, Orbiting Carbon Observatory 3, is being developed for future launch.

A collaboration with Argentina, the Aquarius mission provided the first-ever global maps of salt concentration at the ocean surface following its launch in 2011; it operated until 2015. The Soil Moisture Active Passive mission was designed to provide the first global measurements of soil moisture and surface freeze/thaw information to improve our understanding of how water, energy and carbon are exchanged between Earth's land and atmosphere. Following its launch in 2015, its radiometer stopped functioning later that year, but it continues to deliver science data from its other instrument.

JPL is working with India's space agency to develop an advanced radar imaging satellite to provide an unprecedented, detailed view of Earth. The NASA-ISRO Synthetic Aperture Radar, or NISAR, satellite is designed to observe and take measurements of some of the planet's most complex processes, includ-

ing ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes and landslides.

In cooperation with France and Canada, JPL is working on a satellite designed to make the first-ever global survey of Earth's surface water. The Surface Water and Ocean Topography, or SWOT, satellite will collect detailed measurements of how water bodies on Earth change over time.

Astronomy and Physics

In addition to studying Earth itself and other bodies within the solar system, other JPL missions extend our view deeper into the universe. Many of these have focused on examining the cosmos using infrared light invisible to the human eye.

JPL was U.S. manager of the Infrared Astronomical Satellite, a joint project with the Netherlands and the United Kingdom. Launched in 1983, the mission was an Earth-orbiting telescope that mapped the sky in infrared wavelengths. Its data have led to a wealth of discoveries about the formation of galaxies, stars and planets, including the first-ever direct evidence of an emerging planetary system around a star besides the sun — material orbiting Vega, 26 light-years away.

That mission initiated a rich history of involvement with infrared at the Laboratory. JPL, in conjunction with Caltech, operates the Infrared Processing and Analysis Center, which has processed data for several infrared missions, both spaceborne and ground-based.

That expertise also prepared JPL to develop and manage the Spitzer Space Telescope, a sibling to the Hubble Space Telescope. Spitzer, along with the Hubble Space Telescope, the Chandra X-ray Observatory and the Compton Gamma Ray Observatory, were conceived as part of NASA's Great Observatories Program, designed to study the universe at various wavelengths. Launched August 25, 2003, Spitzer produced a long string of discoveries, ranging from views of the earliest stars in the universe to the revelation that the stuff that comets and planets are made of is common throughout our galaxy. Perhaps most memorably, Spitzer was the first telescope ever to directly capture light from planets orbiting other stars; previously, astronomers could only tell planets were there by their gravitational effect on their parent star. In 2009, Spitzer's coolant was depleted, and it shifted to a new, "warm" mission helping to refine estimates of Hubble's constant, or the rate at which our universe is stretching apart. Astronomers also planned to use it to assess hazards from near-Earth asteroids.

The Two Micron All-Sky Survey was astronomy's most thorough high-resolution digital survey of the entire sky, completed by twin infrared telescopes. Operations began in Arizona in June 1997 and in Chile in March 1998, and observations concluded in February 2001. The survey produced catalogues brimming with nearly half a billion objects. The bonanza of astronomical discoveries includes hundreds of brown dwarfs, or cool, failed

stars, enabling scientists to define new classes of stars; maps of the Milky Way's structure and dust distribution, and large-scale structure in the nearby universe; and observations of numerous dust-obscured galaxies in the distant universe.

In December 2009, NASA launched the JPL-managed Wide-field Infrared Survey Explorer, or WISE, designed to detect hundreds of millions of objects from asteroids to distant galaxies as it maps the entire sky. A thousand times more sensitive than the celebrated Infrared Astronomical Satellite of the 1980s, WISE snapped 1.5 million images — one every 11 seconds — and mapped the sky eight times over during its 10-month mission. After going into hibernation for 2 1/2 years, the spacecraft was reactivated in late 2013 for an extended mission called NeoWISE, in which the spacecraft has turned its attention on near-Earth objects.

Among yet other infrared missions, JPL provided key technologies for the European Space Agency's Herschel and Planck spacecraft, which rode together into space on a single rocket following their launch on an Ariane rocket in May 2009. Both orbit an invisible spot in space called the Lagrange 2 point, four times farther from Earth than the moon. Herschel studied star-forming clouds — the “slow cookers” of star ingredients — to trace how life-forming molecules like water form. Planck took the sharpest portrait ever of the residue of the Big Bang, known as the cosmic microwave background. Both Herschel and Planck completed their missions in 2013.

Other JPL spacecraft and instruments have been designed to study other portions of the energy spectrum. JPL designed and built the Wide Field/Planetary Camera, the main observing instrument on NASA's Hubble Space Telescope. After a flaw was discovered in the space telescope's main mirror, JPL created a second-generation camera, the Wide Field and Planetary Camera 2, that compensated for the optical problem — essentially like fitting Hubble with a set of corrective eyeglasses. Spacewalking astronauts installed this second camera during a shuttle mission in December 1993, allowing Hubble to fulfill its promise in producing unprecedented views of the cosmos. The camera was removed by astronauts and returned to Earth during a shuttle mission in May 2009.

In April 2003, NASA launched the Galaxy Evolution Explorer. This Caltech–JPL mission, developed under NASA's Small Explorer Program, used ultraviolet wavelengths to study the history of star formation. It observed a million galaxies across 10 billion years of cosmic history to help astronomers determine when the stars we see today had their origins. The mission ended in 2013.

JPL managed flight project development of Kepler, a space-based telescope designed to search for Earth-size planets around other stars. Kepler accomplishes this by watching for changes in the light from stars as planets pass in front of them, concentrating on an area of the sky around the constellations Cygnus the Swan and Lyra the Lyre. Following launch in March

2009, JPL handed off science operations to NASA's Ames Research Center, home of the mission's principal investigator. Using data from the mission, scientists have identified more than 4,500 candidate exoplanets, and have confirmed more than 1,000 of these as bona fide planets. A handful of planets are thought to be rocky like Earth (but a bit bigger), and orbit in the habitable zone of their stars, where liquid water — an essential ingredient of life as we know it — might exist.

In 2013, Kepler was assigned a new mission called “K2.” Two of the spacecraft's reaction wheels had failed, so engineers came up with a clever scheme to redesign the mission. K2 still hunts for planets, but it scans a larger swath of sky than before, along the ecliptic plane. The mission has begun new types of research as well, such as the study of objects within our solar system, exploded stars and distant supermassive black holes at the hearts of galaxies.

The Nuclear Spectroscopic Telescope Array, or NuSTAR, launched in 2012 to study the universe in high-energy X-rays to better understand the dynamics of black holes, exploding stars and the most extreme active galaxies. In addition to complementing astrophysics missions studying the universe in various spectra, NuSTAR, the first hard-focusing X-ray telescope to orbit Earth, is greatly improving on observations from ground-based observatories.

JPL is developing the Mid-Infrared Instrument for NASA's James Webb Space Telescope, a successor to Hubble that will look back in time over more than 90 percent of the history of the universe. JPL's instrument will image stars and galaxies in infrared light. Data from the instrument will contribute to investigations about the evolution of the universe and the search for the first-ever episode of star formation, or “first light.” The Webb telescope is under development and working toward a 2018 launch date. JPL also has a major role in NASA's Wide-Field Infrared Survey Telescope, a future mission to study dark energy and extrasolar planets. JPL is contributing starshade technology to allow the telescope to detect exoplanets.

A facility designed to fly aboard the International Space Station, the Cold Atom Laboratory will make use of the space station's unique microgravity environment to observe quantum phenomena that would otherwise be undetectable from Earth. The laboratory will be available for use by multiple scientific investigators and is designed to be maintained on orbit. Scheduled for launch and installment on the International Space Station in 2017, it will also serve as an experiment in the use of laser-cooled atoms for future quantum sensors.

Telecommunications

To provide tracking and communications for planetary spacecraft, JPL designed, built and operates NASA's Deep Space Network of antenna stations.

Communications complexes are located in California's Mojave Desert, in Spain and in Australia. In addition to NASA missions, the network regularly performs tracking for international missions sending spacecraft to deep space. Ground stations also conduct experiments using radar to image planets and asteroids, as well as experiments using the technique of very long baseline interferometry to study extremely distant celestial objects. The Deep Space Network celebrated its 50th anniversary of operations in December 2013.

The Deep Space Network has also supported Space Very Long Baseline Interferometry, a radio astronomy project teaming orbiting spacecraft with ground antennas.

Technologies

In the decades it has led the nation's planetary exploration program, JPL has honed several skills and areas of innovation, including deep space navigation and communication, digital image processing, imaging systems, intelligent automated systems, instrument technology, microelectronics and more. Many of these disciplines found applications outside the planetary spacecraft field, from solar energy to medical imagery.

In the mid-1970s, in response to a world energy crisis, JPL worked to develop and apply alternate sources of electricity such as solar energy, for the Department of Energy, and electric vehicles and other alternative transport systems, for the Department of Transportation.

The Laboratory has also applied space-based operational, communication and information processing techniques to the needs of the Department of Defense, the Federal Aviation Administration and other federal agencies. Its active technology transfer program with the industrial community dates back to the early days of the missile program.

JPL conducts technology development projects both for NASA and for sponsors other than NASA. Non-NASA projects at JPL have included Firefly, an aircraftborne infrared fire mapping system for the U.S. Forest Service; a document-monitoring system to help the National Archives safeguard the U.S. Constitution, Declaration of Independence and Bill of Rights; medical projects such as robot-assisted microsurgery and medical imaging systems, and Internet-based telemedical systems; and projects in such fields as advanced spacecraft and sensor technology, microelectronics, supercomputing and environmental protection.

JPL work for the Department of Defense has included the Miniature Seeker Technology Integration, a satellite built and launched

in November 1992 to demonstrate miniature sensor technology and a rapid development system. JPL also managed the U.S. Army's All Source Analysis System project, a battlefield information management system.

Research and development activities at JPL include an active program of automation and robotics supporting planetary rover missions and NASA's International Space Station program. RoboSimian, a multi-jointed robot sponsored by the U.S. Defense Advanced Research Projects Agency, placed in the top five at a DARPA Robotics Challenge in Pomona, California, in 2015. In supercomputing, JPL pioneered work with new types of massively parallel computers to support processing of enormous quantities of data to be returned by space missions in years to come.

Recent JPL technology projects have included the Low-Density Supersonic Decelerator, which tested technologies to land large planetary payloads in the skies near Kauai, Hawaii; Optical Payload for Lasercomm Science, an experiment launched to the International Space Station in 2014 to demonstrate high-speed video transmission from space using lasers; and Finding Individuals for Disaster and Emergency Response, or Finder, an instrument designed to locate injured people following disasters. It was used successfully to help rescue four men trapped in rubble following a 7.8-magnitude earthquake in Nepal in April 2015.

Institutional

In addition to the Laboratory's main Pasadena site and the three Deep Space Network complexes around the world, JPL installations include an astronomical observatory at Table Mountain, California, and a launch operations site at Cape Canaveral, Florida.

In 2016, JPL has a workforce of about 5,500 employees and on-site contractors, and an annual budget of approximately \$1.8 billion.

Dr. Michael M. Watkins, an engineer and scientist who has had roles on many projects during a 22-year career at the Laboratory, became director of JPL on July 1, 2016. In addition to his JPL post, he serves as a vice president of Caltech. Watkins' predecessors as head of the Laboratory were Dr. Charles Elachi (2001–2016), Dr. Edward C. Stone (1991–2001), Dr. Lew Allen, Jr. (1982–1990), Dr. Bruce Murray (1976–1982), Dr. William H. Pickering (1954–1976), Dr. Louis Dunn (1946–54), Dr. Frank Malina (1944–1946) and Dr. Theodore von Kármán (1944 and forerunner organization).

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